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Ocean Acidification on the Diversity and Abundance of Calcareous Nannofossils and their Interactions with Foraminifera: Implications for Hydrocarbon Exploration

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Abstract

This study investigates the influence of ocean acidification on the diversity, abundance, and preservation of calcareous nannofossils and their interactions with foraminiferal assemblages in the Late Miocene subsurface section of Well A-1, offshore Niger Delta. Detailed biostratigraphic and paleoecological analyses were conducted using microfossil data spanning depths from 11,440 to 12,580 ft. Key assemblage trends, including the decline of *Discoaster* species, shifts in planktic/benthic foraminiferal ratios (P/B ratio), and increasing dominance indices, point to a progressive loss of biodiversity and carbonate saturation with depth—hallmarks of ocean acidification. The upper interval (11,440–11,750 ft) is characterized by high microfossil diversity, warm oligotrophic conditions, and good carbonate preservation. Below 11,750 ft, sensitive taxa such as *Globigerinoides ruber* and *Discoaster spp.* decline sharply, while resilient forms like *Reticulofenestra pseudoumbilicus*, *Uvigerina spp.*, and agglutinated foraminifera dominate, indicating a stressed marine environment. Proxy ratios (%Discoaster, P/B) and dominance index trends align with global Late Miocene acidification events (~7.4–8.5 Ma).These shifts in microfossil communities reflect changes in paleoenvironmental conditions including reduced pH, lower carbonate saturation, and variable productivity. The results have significant implications for hydrocarbon exploration, particularly in identifying potential source rock intervals and carbonate-rich reservoir zones. This research highlights the importance of integrating microfossil-based acidification proxies into paleoenvironmental reconstructions and petroleum system analysis.

Keywords: Calcareous nannofossils; Foraminifera; Diversity indices; Ocean acidification; Paleoenvironment

Introduction

The oceans play a critical role in regulating Earth's climate and carbon cycle. Marine microorganisms such as calcareous nannofossils (e.g., coccolithophores) and foraminifera are key components of this system, contributing significantly to primary production, carbon sequestration, and sediment formation. These calcifying plankton are highly sensitive to changes in ocean chemistry, particularly ocean acidification a process driven by elevated atmospheric CO_2 that lowers seawater pH and reduces carbonate ion availability, impairing calcification.

Throughout geological history, several global events such as the Paleocene-Eocene Thermal Maximum (PETM), Oceanic Anoxic Events (OAEs), and mass extinctions have been linked to rapid environmental perturbations, including ocean acidification. These events often coincide with substantial changes in the diversity, abundance, and preservation of calcareous microfossils. The fossil record of these organisms, preserved in marine sediments, offers a valuable archive for reconstructing past acidification episodes and assessing their ecological impacts.

Understanding how past ocean acidification affected calcareous nannofossils and foraminifera is essential for both paleoenvironmental reconstruction and applied geosciences, particularly in hydrocarbon exploration. Changes in microfossil assemblages can serve as biostratigraphic markers, inform depositional environment interpretations, and help identify source rock and reservoir intervals. Furthermore, interactions between nannofossils and foraminifera whether competitive, synergistic, or ecologically decoupled can provide insights into ecosystem resilience under stress, offering analogues for present and future ocean changes.

Despite their importance, there remains a knowledge gap in understanding how acidification-driven changes in calcareous plankton communities affect sedimentation patterns and stratigraphy in petroleum-bearing basins. Current exploration models often overlook the role of these environmental stressors in shaping microfossil distributions, leading to potential misinterpretation of depositional environments or source rock intervals. Moreover, the ecological interactions between nannofossils and foraminifera during periods of environmental stress are underexplored, despite their combined contribution to carbonate sedimentation and petroleum system elements.

This study aim to bridge micropaleontology with exploration geology by investigating the impacts of historical ocean acidification on nannofossil-foraminifera dynamics and their implications for hydrocarbon system evaluation. This involves analysis of the diversity and abundance of calcareous nannofossils and foraminifera across selected historical ocean acidification events using ditch cutting samples from hydrocarbon-bearing basins, evaluate the ecological relationships and to identify and interpret the paleoenvironmental conditions (e.g., pH, productivity, carbonate saturation) associated with observed shifts in microfossil assemblages. To improve the reliability of micropaleontological data in exploration, there is a need to assess how acidification has historically altered microfossil communities and how these changes manifest in the rock record. Without this understanding, critical paleoenvironmental indicators may be misread, affecting decisions in hydrocarbon prospecting and reservoir characterization.

Geology of the Study Area

Niger Delta is located on the continental margin of Southern Nigeria and covers an area of 70km. It lies between longitude 5^0E and 8^0E and latitudes 30^0 and 60^0 Short and Stable (1997). Stable mega tectonic framework such as the Benin and Calabar flank mark the northewest and eastern boundaries. The Anambra basin and the Abakaliki high mark the northern boundary and it is bounded to the south by the west of guinea. The stratigraphic fill of the Niger Delta basin is composed primarily of three lithostratigraphic units that extend across the whole delta (Obafemi et al. 2020). These include basal marine pro-delta Akata Formation, the middle shallow-marine delta front Agbada Formation and, the overlying youngest continental, delta plain Benin Formation (Doust and Omatsola 1990; Adojoh et al. 2020). The Akata Formation, a prodeltaic lithofacies of Paleocene to Recent in age is composed primarily of marine shales with turbidite sands and continental slope channel fills (Doust and Omatsola 1990). It is estimated to be up to 7 km thick and generally considered as the source rock of the Niger Delta. The middle paralic Agbada Formation, estimated to be over 3.7km thick and ranges in age from Eocene to Recent (Tuttle et.al., 1999; Avbovbo, 1978) is primarily composed of delta-front lithofacies and characterized by intercalations of sand and shale. The sandstone reservoirs facies within this formation are mostly shoreface and channel sands with minor shales in the upper part, and alternation of sands and shales in the lower part (Doust and Omatsola 1990). This unit serves as the hydrocarbon reservoir within the basin with sand percentage ranging from 30 to 70% (Doust and Omatsola 1990; Igili, and Ndubueze (2024). The deltaic sequence is capped by the topmost Benin Formation that is Oligocene to Recent in age, about 2km thick and is made up of continental fluvial sands (Avbovbo 1978; Doust and Omatsola 1990; Owolabi et al. 2019). Adegoke et al. (2017) described the formation as friable, white, fine to coarse and pebbly, poorly sorted sands, with lignites occurring as thin streaks or as finely dispersed fragments.

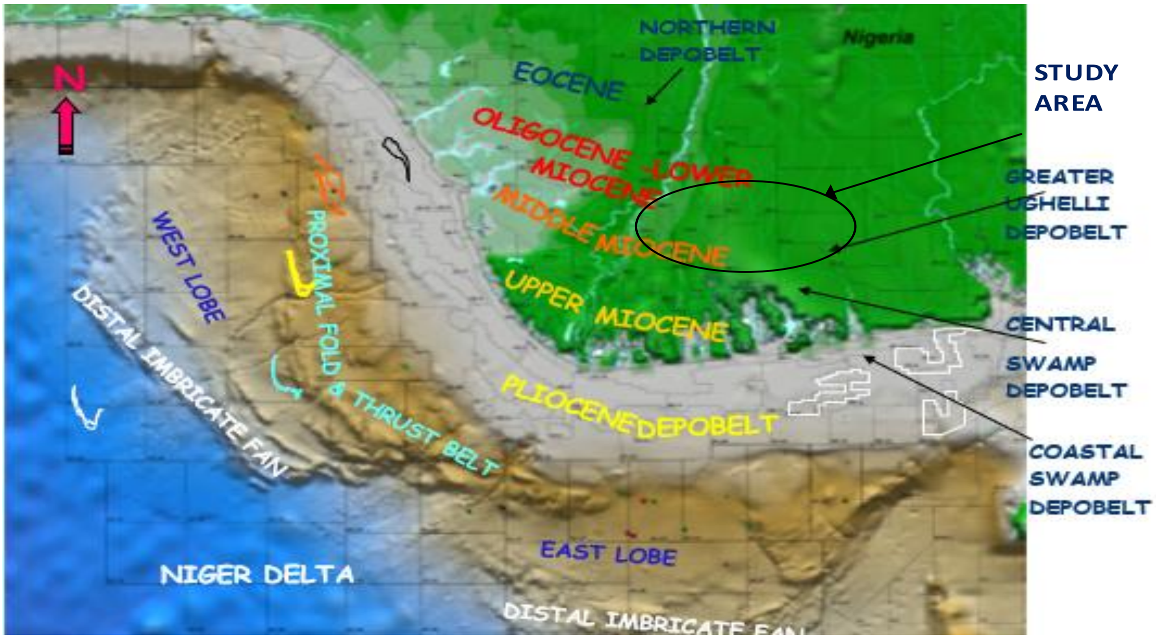

Fig. 1. Geologic map of the Niger Delta Region showing the study area.

Materials and Method

Materials

An aggregate total number of sixty (60) ditch cuttings from intervals 11140 – 12580 ft of well A and 11620 – 13570 ft of well B drilled in the Niger Delta were utilized for this study. Other materials used includes: charts, microscope and camera, and computer software (Stratabug, Corel draw, Surfer and Microsoft Excel). Laboratory analysis was carried out in Crystal Age Laboratory Lagos and Novena University Ogume. The Niger Delta where the studied wells were located is shown in Figure 3 as the actual locations of the wells were not made available for proprietary reasons.

Methods

The following methods were adopted for this research: acid method of biofacies recovery, microscopic study, lithologic description of the ditch cuttings. The methods employed in this work include: Sample preparation, description, picking and analysis**.**

Calcareous Nannofossils Sample Preparation Procedures.

A slight modification of the standard smear slide preparation was employed. About 5 gm of cuttings was measured and dried, the material was gently crushed using mortal and pestle (for shaly samples). The samples were treated with hydrogen peroxide to remove organic matter, washed with distilled water and dried again.

Slide Preparation:

Small amount of the processed sample with distilled water. Crushed material was dispersed in distilled water in a tube. Pipette a few drops of the mixture onto a glass slide. A disposable glass pipette was employed to pipette the suspension for final slide making. The pipetted solvent was dried on a 22 x 40mm cover slip at a slightly hot temperature normally 40° - 50°C. Allow the mixture to dry completely. Fix the sample with a few drops of Canada balsam or equivalent. The dried cover slip was then mounted on a glass slide using the Norland adhesive mounting medium and cured under the UV-light. For Data Interpretation Standard nannofossil zonation for all samples making use of the schemes of Martini (1971), Okada and Bukry (1980) and nannotax.org website was employed.

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Analysis/Interpretation

For Data Interpretation Standard nannofossil zonation for all samples making use of the schemes of Martini (1971), Okada and Bukry (1980) and nannotax.org website was employed.

Micropaleontological Sample Preparation Procedures:

Samples were weighed (25gm) and ready for soaking. Soaking and Decanting Samples were soaked in liquid soap and left overnight to disaggregate. Samples were washed with water through 63 micron sieve and dried. Samples were packaged in one plastic bag and labeled properly. Packaged samples were made ready for picking. All foraminifera and accessory microfauna were picked using a reflected light stereobinocular microscope (SZX9, SZX12 and SZ61 Olympus Microscope into microfauna cellules.

Micropaleontological analysis was carried out by determining foraminifera specimens to the generic and/or specific level using the reflected light binocular microscope listed above.

Results and Discussion

From the results in fig. 1 below (calcareous nannofossils charts), the intervals is characterized by fair to common distribution of calcareous nannofossils over the upper interval 11140 – 11680 ft. The occurrence of *Discoaster hamatus* and *Catinaster coalitus* in sample 11250 ft.

Others include *Discoaster bollii, Discoaster, Catinaster coalitus, Reticulofenestra pseudoumbilicus, Sphenolithus moriformis, Coccolithus pelagicus* and *Helicosphaera carteri.* Interval 11680 – 12580 ft is characterized by rare and scattered occurrence of non-age and –zonal diagnostic taxa including *Sphenolithus moriformis, Reticulofenestra spp, Helicosphaera carteri Reticulofenestra pseudoumbilicus* and *Coccolithus pelagicus*.

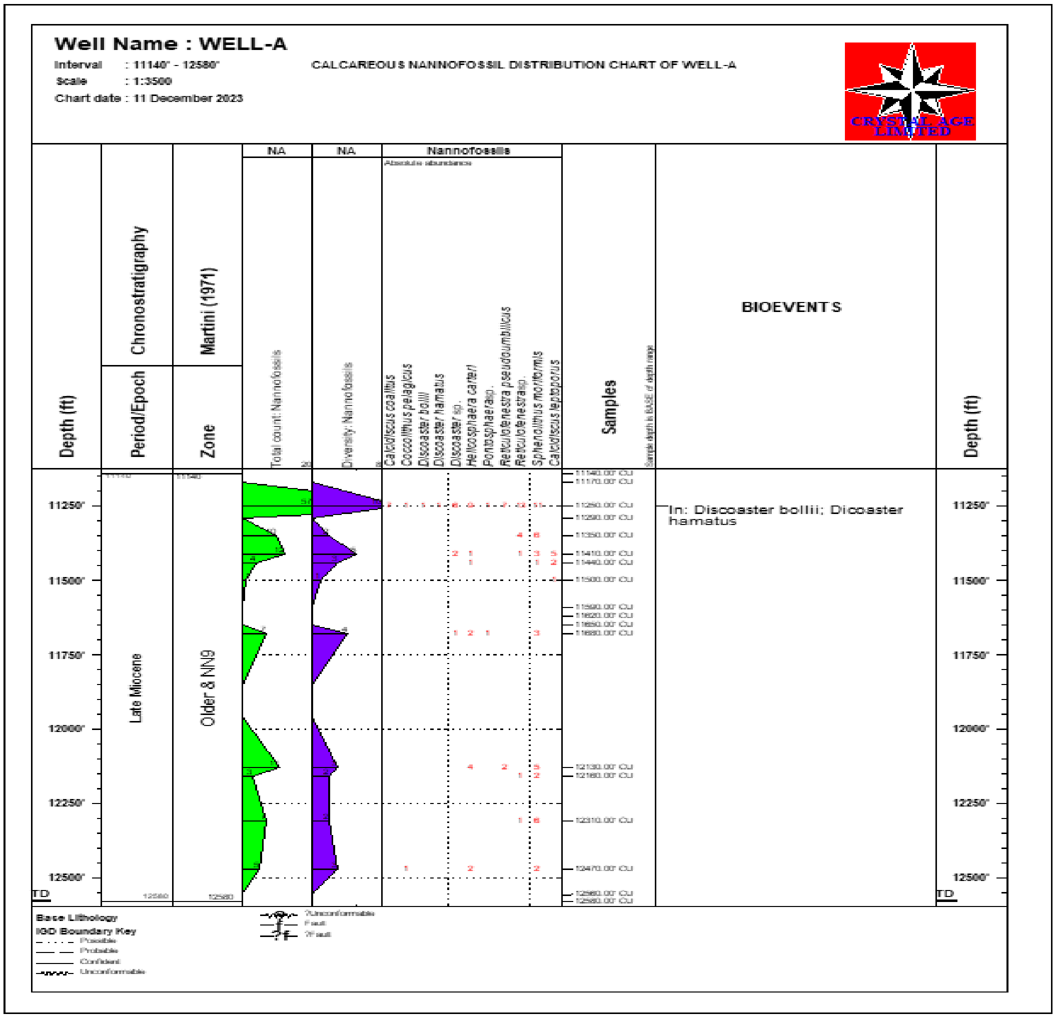

Fig. 2 Showing calcareous nannofossil distribution chart

From fig. 2, (foraminifera charts), the section is moderately fossiliferous within 11250 – 11680 ft where foraminiferal assemblages consisting of 12 calcareous, 6 planktic and 4 arenaceous species were recovered. Identified species include; Calcareous species: *Lenticulina inornata, Epistominella vitrea, Heterolepa pseudoungeriana, Heterolepa perlucida, Lenticulina costata, Quinqueloculina lamarckiana, Q. microcostata, Amphicoryna* *scalaris caudata, Uvigerina subperegrina* and *Bolivina* spp.

Planktic species: *Globigerinoides trilobus immaturus, Globigerinoide sobliquus extremus, Sphaeroidinellopsis seminulina, Orbulina universa.*

Arenaceous species: *Alveolophragmium crassum, Cyclammina cancellata, Haplophragmoides* spp. *and Textularia* spp.

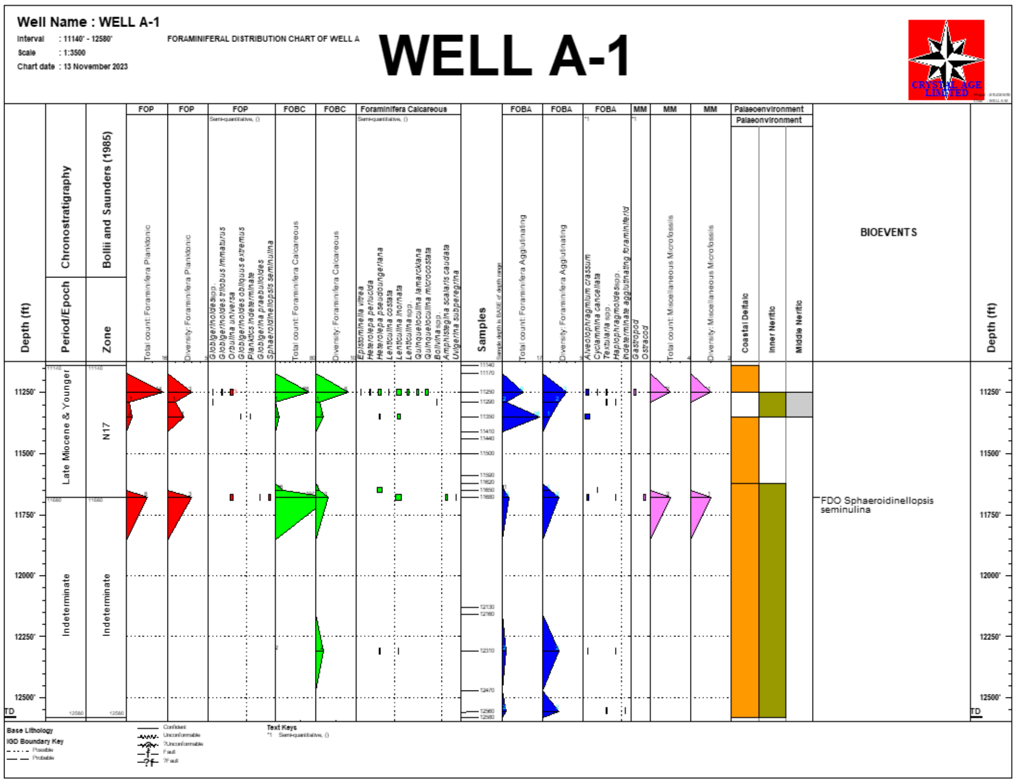

Fig. 3 Showing foraminifera distribution chart

The impacts on calcareous nannofossil and foraminiferal diversity and abundance are particularly critical since these groups are essential indicators of past environmental conditions and play key roles in marine carbon cycling. To deduce the impact of ocean acidification on the diversity and abundance of foraminifera, it is pertinent to analyzed how these organisms responds to changing carbonate chemistry in seawater. Ocean acidification, which results primarily from increased atmospheric carbon dioxide (CO_2), leads to lower pH levels in ocean waters and a decrease in the availability of carbonate ions.

Fossils responses to Ocean Acidification

Foraminifera, protists with calcareous shells, are particularly sensitive to changes in these conditions. Historical ocean acidification is also expected to have affected the diversity and abundance of foraminifera, particularly those with calcareous shells. Species such as *Lenticulina inornata, Epistominella vitrea, Heterolepa pseudoungeriana, Heterolepa perlucida, Globigerinoides trilobus immaturus, Globigerinoide sobliquus extremus* are expected to have been adversely affected by historical ocean acidification, with potential reductions in their calcification rates and abundance (Kuroyanagi et al., 2009). In contrast, species with agglutinated shells, such as *Alveolophragmium crissum, Cyclammina cancellata, Haplophragmoides spp., Textularia spp*. may have been less affected by historical ocean acidification (Kuroyanagi et al., 2009).

Ocean acidification is expected to have negatively impacted the diversity and abundance of calcareous nannofossils, particularly those with heavily calcified shells. Species such as *Discoaster hamatus, Discoaster bollii, Catinaster coalitus, Reticulofenestra pseudoumbilicus* are expected to have been adversely affected by historical ocean acidification, with potential reductions in their calcification rates and abundance (Beaufort et al., 2011; Iglesias-Rodriguez et al., 2008). In contrast, species with lighter calcification, such as: *Sphenolithus moriformis, Coccolithus pelagicus, Helicosphaera carteri* may have been less affected or even beneficially affected by historical ocean acidification (Beaufort et al., 2011).

Diversity Indices

From the Foraminifera chart, two bio-zones was identified was identified including Zone N17 of Late Miocene and Younger at 11,440 ft to 11,750ft characterized with high diversity and abundance of planktonic forams *Globorotalia spp., Orbulina spp* dominance of calcareous forms. Intermediate zone below 11,750ft with reduction in both planktonic and calcareous bentics. Agglutinated forms of *Ammobaculites, Trochammina* occurs sparsely with presence of FDO of *Sphaeroidinellopsis seminulina* at 12,250ft. Their relative abundances are shown in table 1 and 2. Using Shannon H' proxy for Foraminifera computed from the three foram groups (planktonic, benthic, calcareous). The proxy shows *peaks and troughs* down the section fig 4. Certain depth interval show higher diversity (higher H') while others are reduced. Higher foram H' suggests more mixed assemblages and ecological niches; lower H' suggests environmental stress or dominance by fewer taxa. The section is dominance of Calcareous planktonic foraminifera with high abundance and diversity in shallower section (above 11750 ft) drops significantly below this depth. The Agglutinated Forms appear mostly in deeper intervals (11750–12580 ft), especially where calcareous forms decline. Calcareous Benthics also dominant in upper sections. Intervals with reduced diversity experienced stress events possibly increased acidification episodes, productivity collapse, or stratification events that favor specific taxa.

Table 1 Planktonic Foraminifera (Calcareous) and Calcareous Nannofossils

Taxa	**Relative Abundance**	**Diversity**	**Depth Range (ft)**
High abundance of	Moderate-High	Moderate	11,440 – 11750
Coccolithus, R. pseudoumbilicus, Calcidiscus leptoporus, Coccolithus pelagicus			
Globigerinoides ruber	High	High	11,750 – 12,250
Less *Discoaster* spp., *Reticulofenestra*	moderate	moderate	
Globigerinoides sacculifer	High	High	12,250– 11750
Orbulina universa	Moderate	Low-Moderate	11,440 – 11750
Discoaster spp., *Sphenolithus abies*	Low	Sparse	
Globigerina bulloides	Low	Low	Scattered

Table. 2 Benthic Foraminifera (Calcareous and Agglutinated)

Taxa	**Type**	**Relative Abundance**	**Diversity**	**Depth Range (ft)**
Cibicides spp.	Calcareous	Moderate	Moderate	11440–11750
Uvigerina spp.	Calcareous	Moderate	Low-Moderate	11440–11750
Lenticulina spp.	Calcareous	Low	Low	11750–12200
Trochammina spp.	Agglutinated	Low	Low	11750–12250
Ammobaculites spp.	Agglutinated	Sparse	Very Low	11750–12400
Textularia spp.	Agglutinated	Sparse	Very Low	11750–12580

From table 1 and 2 above, the highest planktonic abundance is seen in the top 300 ft (11440–11750 ft). Agglutinated foraminifera increase slightly in the lower part (depths below 11750 ft), but overall remain in low abundance. Calcareous foraminifera and heavily calcifed nannofossils of *Coccolithus*, *R. pseudoumbilicus, Calcidiscus leptoporus, Coccolithus pelagicus* dominated the upper sections with clear diversity and relative abundance.

At 11440-11750, there was high diversity of planktics and nanno fossils with *Globigerinoides ruber, Discoaster spp* as dominant taxa. Moderate to decline diversity between 11750–12250 with *Uvigerina spp., Reticulofenestra spp.as* dominant taxa, while >12250 is characterized with low, dominance of resilient forms *R. pseudoumbilicus,* agglutinated benthics. The diversity, dominance of *R. pseudoumbilicus* and *Coccolithus Discoaster spp.* and sensitive planktonic foraminifera exhibit marked decline below 11750 ft. Increasing dominance index (DI > 0.5) signals loss of biodiversity consistent with acidification stress. This could possibly due to acidic/undersaturated water or poor preservation. These indices can reveal biodiversity loss or shifts, which are typical ecological responses to acidification.

Ecological and Functional Group

Upper section (11440–11750 ft**)** was dominated by surface dwellers characterized with *Globigerinoides ruber, O. universa, Discoaster, Coccolithus pelagicus, R. pseudoumbilicus* suggesting warm, stratified water column, while deeper intervals demonstrated sharp decline characterized with *Globorotalia Menardii, G. Truncatulinoides, Reticulofenestra, Coccolithus pelagicus, Uvigerina, Discoaster spp., Sphenolithus abies* suggests reduced water column stratification, less stable conditions associated with thermocline or nutrient-rich waters. Transition from oligotrophic associated with low-nutrient, open ocean conditions and well oxygenated environment characterized with forams such as *Globigerinoides ruber*, *Orbulina and calcareous nannofossils* were *Discoaster* abundance peaks at 11250 ft to eutrophic with characteristics forms *Uvigerina spp., Globigerina bulloides* indicators suggests increasing nutrient availability, likely tied to coastal influence or upwelling. Also deeper intervals show fewer heavily calcified forms such as *Cibicides, Globorotalia menardii*, suggesting lower carbonate saturation and potential undersaturation in deeper waters. Acidification tends to reduce heavily calcified, oligotrophic taxa and favor opportunistic, lightly calcified ones. Intervals where planktonic and nanno abundance rise together fig. 4 point to higher surface productivity (possibly eutrophic surface conditions). When benthic declines coincide, it suggests stratification with poor bottom-water exchange or acid/dissolution conditions at seafloor.

Morphologically, over-etching, breakage and thinning are more common in deeper agglutinated zones, suggesting poor preservation or post-depositional dissolution, possibly due to reworking, mechanical stress or an indicative of corrosive water, low pH, or undersaturation. Poor preservation, especially of delicate taxa, can be a proxy for low carbonate saturation and therefore acidification.

Paleoenvironmental Conditions

pH Conditions showed from the Upper Section (11440–11750 ft) presence of calcareous forms and good preservation indicating normal marine pH (7.8–8.2), no significant dissolution, while deeper Section (>11750 ft) showed poor preservation, thinning, and more agglutinated forams suggests lower pH, possible acidic conditions, carbonate undersaturation. Also, Dominance of *Globigerinoides* oligotrophic to mesotrophic at the Upper section suggest low productivity which increases significantly at towards the deeper section with presence of *Uvigerina* and agglutinated forms. The shallower section (11440–11750 ft) is characterized with rich calcareous assemblage of high carbonate saturation unlike deeper depths (below 11750 ft) with increase agglutinated taxa, thinning and over-etching suggesting carbonate undersaturation**,** limiting preservation of calcareous shells.

Abundance and Assemblage shift

Using Planktic Foraminifera sensitive taxa of *Globigerinoides ruber*, *Orbulina universa* which decline below 11750 ft. as shown in table 2, resilient taxa of *Uvigerina*, agglutinated forms which increase in relative abundance and Nannofossils *Discoaster* spp which Decline rapidly below 11750 ft. implying classic acidification proxy and *Reticulofenestra spp***.**, *Coccolithus pelagicus* with its increase, showing tolerance to lower pH. Intervals 11440 – 11750 ft experienced high diversit and balance assemblage (oligotrophic), 11,750 – 12,200 is characterized with decrease in sensitive planktonics and discoasters, increase in opportunistic benthics and coccoliths. While intervals below 12,200 ft. is characterized with Low-diversity assemblage dominated by acidification-resilient species. This shift indicates environmental stress likely from ocean acidification, reducing carbonate saturation and affecting shell-secreting microfossils since *Discoasters* decline during acidification due to thin, lightly calcified plates. Decreasing % Discoasters and P/B ratio table 3 and fig 4 below 11750 ft are consistent with acidification and stratification breakdown, reflects a transition from a warm, oligotrophic marine setting to a more stressed, eutrophic or acidified environment**.** The stacked histogram for forams shows relative increases in planktonic (red) vs benthic (blue) in specific early intervals (11440 – 11750) (notably a mid-section peak of planktonic abundance), and intervals where benthic signal is stronger. This suggest interpret as stronger surface productivity and decreased benthic habitat suitability. Nannofossil total abundance proxy shows peaks in a few early intervals and low values in others; Discoaster proxies fig 4c (red dots) appear concentrated in some the middle where nanno total is moderate-to-high. Changes in nanno abundance and Discoaster frequency indicate shifts in surface conditions (temperature, nutrient regime, carbonate chemistry).

The appearance of acidification proxies (Discoaster decline, P/B ratio drop) aligns with Late Miocene Carbonate Crash events (~7.4–7.0 Ma)**.** This coincides with known ocean acidification pulses due to global climate cooling and increased CO_2 offering biostratigraphic and paleoenvironmental correlation**.**

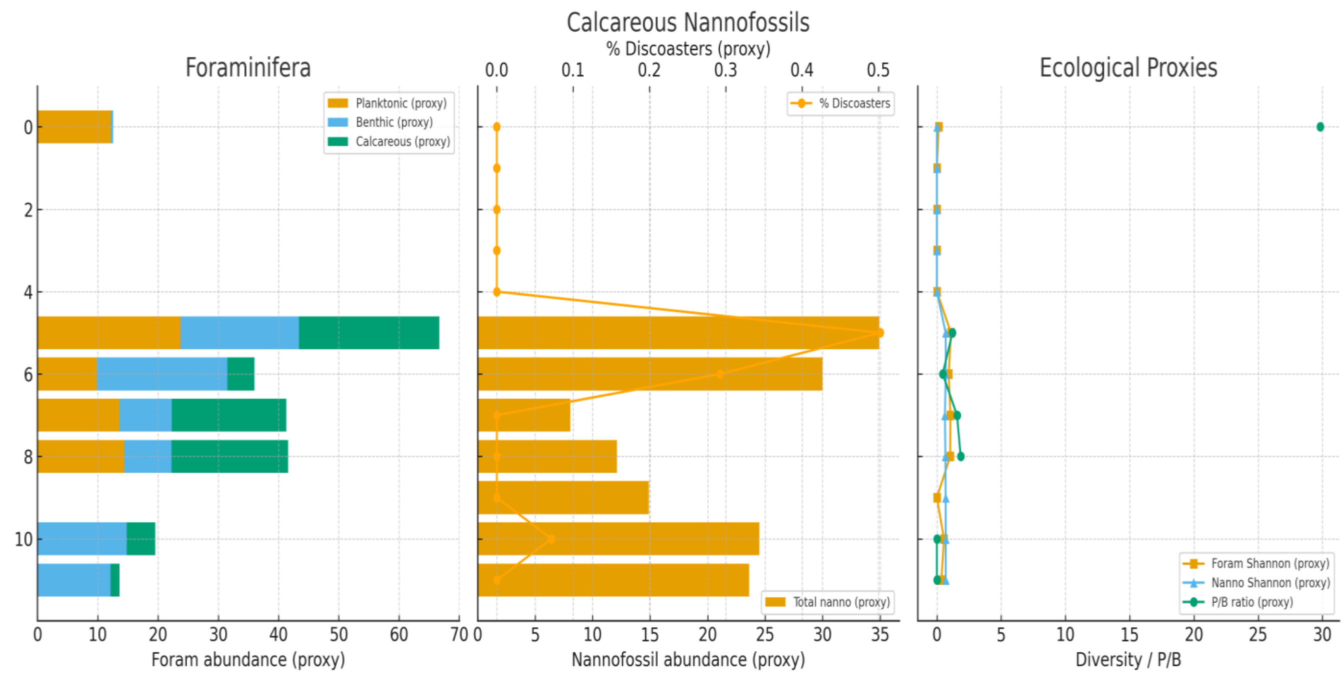

Fig 4 showing relative abundances, Shannon diversity (H') proxies for foram and nanno assemblages, % Discoasters

Table 3 Proxy Ratios for Ocean Acidification and Stratification

Discoaster / Total Nannofossils Ratio (%Discoasters)		
Depth (ft)	**% Discoaster spp.**	**Interpretation**
11440 – 11750	15 – 20%	Good carbonate saturation; warm waters
11750 – 12250	5 – 10%	Onset of acidification
>12250	0 – 2%	Severe acidification/carbonate undersaturation
Planktic/Benthic Foraminifera Ratio (P/B Ratio) **Proxy for water column stratification and surface productivity**		
Depth (ft)	**P/B Ratio**	**Interpretation**
11440 – 11750	>3.0	Stratified water column, high surface productivity
11750 – 12250	1.5 – 2.0	Reduced stratification; decline surface productivity
>12250	<1.0	Mixed water column; collapse of planktonic fauna

Interactions between Nannofossils and Foraminifera

The interactions between calcareous nannofossils and foraminifera play a vital role in the marine ecosystem. Foraminifera often rely on nannofossils as food sources, thus a decline in nannofossil populations could lead to a cascading effect on foraminifera diversity and abundance. As ocean acidification reduced the abundance of specific nannofossil species, it likely impacted the productivity and growth rates of foraminifera groups due to lower food availability (Drennan et al., 2016). The dynamic between calcareous nannofossils and foraminifera became increasingly complex. In many cases, the decline of calcifying nannoplankton likely led to competitive advantages for certain foraminifera groups that could adapt to changing conditions, fostering shifts in community structure (Zachos et al., 2008).

This synthesis shows the intricate relationships between ocean acidification, calcareous nannofossil and foraminifera diversity, and ecological interactions, underscoring the importance of these interactions in understanding past marine environments.

Implication for Hydrocarbon Exploration

Reservoir Quality can be analyze through calcareous microfossil-rich intervals (11440–11750 ft) reflecting carbonate-rich facies conducive to reservoir development. Acidification intervals indicate reduced carbonate accumulation, increasing siliciclastic dominance and affecting porosity. Eutrophic assemblages (*Uvigerina*, *Coccolithus*) correlate with high organic productivity and are Source Rock Potential**,** especially in transitional intervals (11750–12200 ft). Paleo-water Chemistry: Acidification trends may mark transgressive-regressive cycles and oceanic anoxic events**,** guiding sequence stratigraphic models.

Conclusion

The integrated analysis of calcareous nannofossils and foraminifera from Well A-1 reveals that ocean acidification during the Late Miocene had a profound impact on microfossil diversity, abundance, and preservation. It showed a biodiversity loss linked to acidification through a progressive decline in sensitive microfossil taxa such as *Discoaster spp.* and planktic foraminifera below 11,750 ft. which is consistent with reduced carbonate saturation and pH, indicating ocean acidification events. Dominance of resilient assemblages such as increased abundance of dissolution-resistant nannofossils (*Reticulofenestra spp.*, *Coccolithus pelagicus*) and benthic foraminifera (*Uvigerina spp.*, agglutinated forms) reflects ecological adaptation to acidified, possibly eutrophic bottom waters. Also, proxy ratios support acidification trends through the decrease in %*Discoaster* and P/B ratios with depth, along with rising dominance indices, clearly mark acidification-driven environmental stress. Key bioevents such as the last occurrence of *Discoaster bollii* and first downhole occurrence of *Sphaeroidinellopsis seminulina* correspond to globally recognized Late Miocene carbonate crash events, providing a reliable chronostratigraphic framework. The paleoenvironmental transitions identified in this study assist in predicting organic-rich intervals (source rock potential) and carbonate-rich reservoir zones, particularly in the upper, well-preserved interval. In conclusion, microfossil assemblages serve as effective proxies for tracking past acidification events and reconstructing paleoceanographic conditions critical to hydrocarbon exploration. This study relates the necessity of integrating micropaleontology into broader basin analysis and stratigraphic modeling in frontier hydrocarbon regions.

Declaration of Conflict of Interest: Authors have declared that no competing interests exist. Data *Availability Statement:* Data are available upon request from the first author

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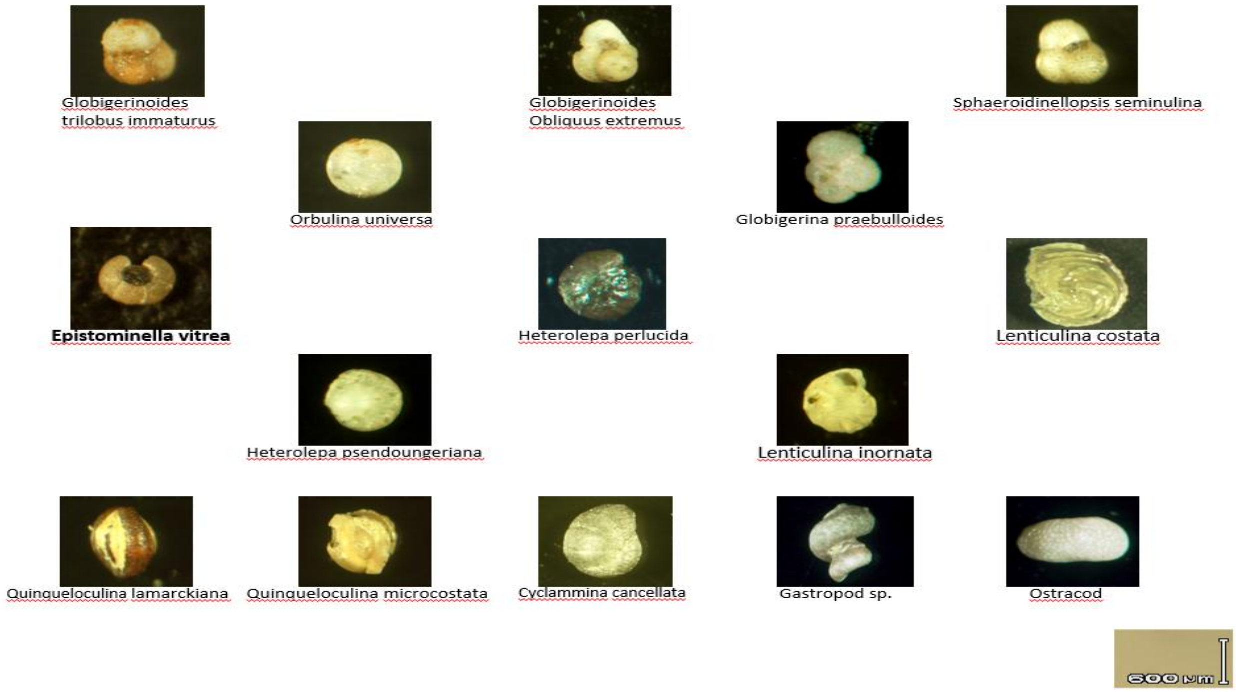
FORAMINIFERA PHOTOGRAPHS FOR WELL A



CALCAREOUS NANNOFOSSIL PHOTOGRAPHS FOR WELL A